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SERVICE ARTICLE

EFFECTS OF HIGH-INTENSITY NOISE
ON NAVAL PERSONNEL

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BEGINNING in 1952, several studies were made of the effects on naval personnel of the operation of jet airplanes from the decks of aircraft carriers, because questions had arisen as to what effect the exposure to high-intensity noise would have on the flight deck personnel. In 1953 a broad, exploratory study, now known as the BENOX study, was made of the biological effects of noise on man. The BENOX Report,[1] was reviewed and commented upon by the then newly formed Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics (CHABA),[2] and recommendations were developed for research in this area. Both the BENOX Report and the CHABA commentary expressed the fear that exposure to jet engine noise in the unexplored range above 140 decibels might actually be producing injurious cumulative aftereffects. The Auditory and Non-Auditory Effects of High-Intensity Noise (ANEHIN) Project* was organized in April 1954 to study the problem that was stated so clearly in the above-mentioned reports.
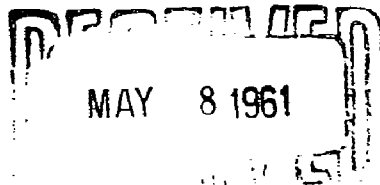
NATURE OF THE PROGRAM

The project was conceived and planned as a field study, first to identify and thereby protect those individuals who might actually be suffering injurious effects, and second because it seemed impossible to bring into the laboratory both the noise exposures and the other stresses of actual military duty that

might combine with noise to µ·oau   aftereffects such as chronic‚ anxiety or undue fatigue. The location selected for the field study, was the flight deck of aircraft carriers where the personnel for‚ ward of the island are exposed to particularly high noise levels. The study later was extended to include land-based maintenance personnel who serviced high-performance jet-powered aircraft. These two categories suffer the most severe sustained noise exposures regularly encountered in line of military duty.

Program Objectives

Except for the familiar impairment of hearing for high frequency sounds, the nature of the cumulative ill effects that were sought by the ANEHIN Project was not known in advance. The only clear specification was to look for undesirable *cumulative aftereffects*. It was never part of the ANEHIN objective to study the impairment of performance that may occur *during* noise exposure. This was conceived as a separate problem that might well be attacked as a laboratory experiment rather than as a field study. In other words, the ANEHIN Project was a wide-spreading "trouble hunt," in which the testing "net" was designed to cover as many aspects as possible. For this reason, a large variety of tests and procedures in addition to audiometry were employed to detect possible changes in sensory and psychomotor performance, equilibrium, central nervous and complex intellectual functions, anxiety, motivation, and the incidence of sick calls and accidents.

In planning the project, the inclusion of physiologic indicators of stress also was considered very carefully, particularly those that involve the activity of the adrenal gland, together with certain recognized medical indicators such as might be revealed by complete neurologic examinations. Another area of possible test and study was social and group behavior. Such studies were deferred, although not rejected outright, because of the elaborate and expensive nature of some of the procedures that would have been involved, on the one hand, and because, in the case of the physiologic indicators, it soon appeared that the degree of stress involved in the actual noise exposures was insufficient to create any real probability of obtaining positive results.

The ANEHIN Project actually became more ᴜhan a search for the effects of high-intensity noise. It became a prototype of any similar trouble hunt that might be indicated at a later time in relation to any other new stress that may be created for personnel by future developments in the weapons and operations of modern warfare. The ANEHIN effort to carry out such a trouble hunt in the form of a field study has revealed certain difficulties and limitations inherent in any field study which, in spite of the consistently fine co-operation that the project received both on shipboard and on shore, seriously limited the scope and the significance of its actual findings. Field studies have their place, but they are expensive and time consuming and the un-

avoidable limitations imposed by operational considerations may seriously impair the scientific value of the entire effort.

ANEHIN CONTRIBUTIONS TO FUTURE RESEARCH

Test Batteries

As a positive contribution to any subsequent trouble hunt, the ANEHIN Project leaves a battery of physiologic, psychologic, and psychomotor tests and a group of questionnaires and pencil-and-paper tests of proved practicality and reliability. Significant progress was made toward the development of a standardized psychiatric interview and a rating scale based on the information so obtained. The tests cover a wide variety of functions and behavior. So wide is this variety that, in spite of the obvious holes in any system of screening, we believe that the probability of detecting undesired cumulative aftereffects of any sort is actually very high. Of course, in any other application, such as to the problems of vibration which may soon beset us in the future, special tests of any particular motor, sensory, or medical function that may be obviously endangered or already definitely implicated would be substituted for the audiometry that was emphasized in the ANEHIN Project.

New Test Equipment

As tools to be used in the search for cumulative aftereffects of high-intensity noise, a mobile laboratory and two new instruments were developed. All three may have a fairly wide application and significance in future work in this area.

1. *The mobile laboratory.* A mobile laboratory was developed to house the audiometric, the physiologic, and the psychologic apparatus, and to provide the proper environment for such tests in the field. In our trailer-mounted, sound-treated laboratory* (fig. 1), it was possible to make satisfactory audiometric measurements and to conduct psychophysiologic tests on the hangar deck of an aircraft carrier during training operations at sea. To provide adequate acoustic environment for audiometric testing in such a situation was no mean accomplishment from the point of view of accoustic engineering.

2. *The group audiometer.* One of the new instruments developed for this study is a group audiometer that employs the psychophysical method of single descent.* This instrument is designed to test 10 subjects at a time. It is semiautomatic, and in its full and final form includes an automatic print-out device that prints immediately the hearing losses of the 10 subjects in 10 typewritten columns (fig. 2). Audiograms for both ears of 10 men can be obtained in from 10 to 15 minutes. Fortunately, and somewhat unexpectedly, the method of single descent as incorporated in this audiometer has proved not only reliable but valid. The actual threshold values agree closely enough with the threshold values
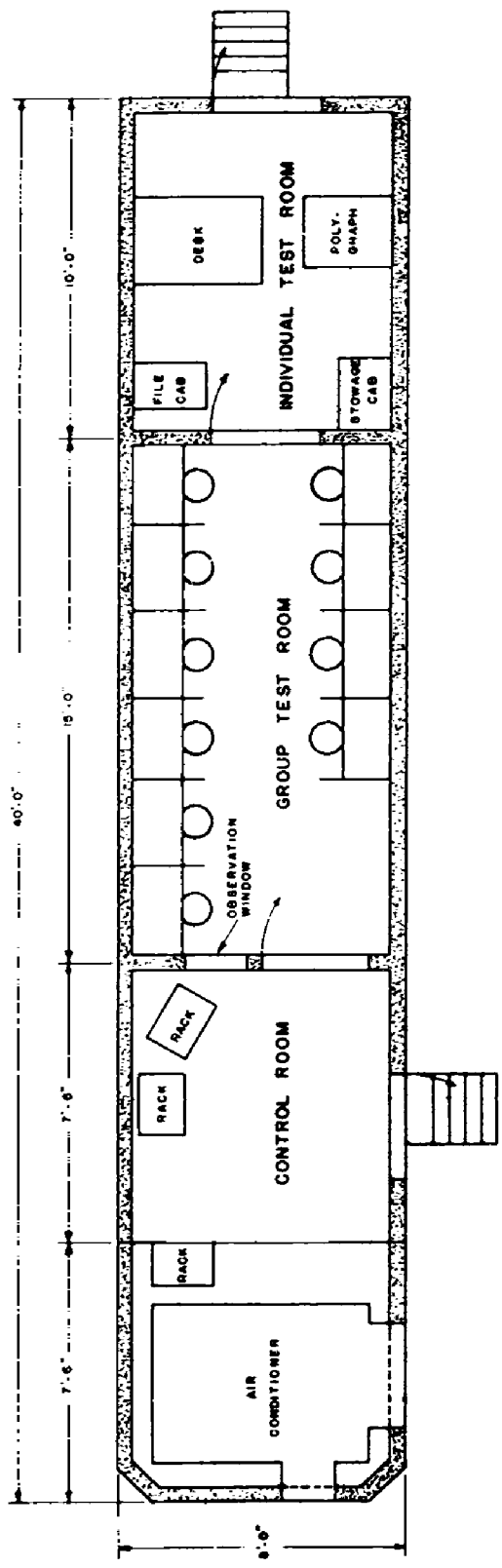
Figure 1. The floor plan of the mobile laboratory for auditory and nonauditory testing. The center room contains stools and testing desks for group tests of 10 men at a time. The laboratory has soundproofed walls and doors, and is air-conditioned throughout.

determined by the accepted standard methods of clinical audiometry to make it legitimate to consider the ANEHIN Group Audiometer for routine use in monitoring audiometry. Further

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	1	2	3	4	5	6	7	8	9	10
250 R	30	00	42	42	30	42	36	00	36	46
	30	00	40	46	32	38	30	00	34	40
250 L	32	00	34	44	28	40	44	00	32	30
	32	00	36	42	28	38	40	00	34	36
500 R	48	00	56	54	44	54	62	00	46	56
	48	00	58	54	46	54	64	00	50	56
500 L	50	00	46	68	46	56	58	00	42	56
	48	00	48	66	40	54	56	00	50	56
1000 R	54	00	62	74	50	60	64	00	56	64
	54	00	70	76	44	62	68	00	58	66
1000 L	52	00	64	64	50	60	68	00	60	64
	52	00	66	78	42	60	68	00	56	62
2000 R	58	00	58	90	52	64	76	00	66	66
	58	00	58	72	56	58	70	00	62	64
	60	00	60	70	54	64	72	00	58	62
2000 L	60	00	64	76	56	50	70	00	60	62
	52	00	58	68	46	52	70	00	54	54
4000 R	40	00	62	78	44	54	70	00	58	60
	42	00	60	80	40	58	72	00	62	60
4000 L	36	00	58	68	42	54	58	00	66	56
	38	00	50	70	46	50	64	00	70	56
8000 R	00	00	26	54	00	50	42	00	46	48
	00	00	20	52	00	48	44	00	46	52
8000 L	16	00	18	52	14	44	48	00	48	50
	08	00	14	46	10	42	46	00	48	48

1　FMB
2　Unoccupied
3　DLW
4　JIC
5　JDH
6　LMR
7　WG
8　Unoccupied
9　WM
10　RWP

Figure 2. Sample data sheet from the Automatic Audiometric Data System (AADS). The two-digit numbers in the 10 columns are typed automatically. The operator makes all other entries. Readings are in thresholds expressed in decibels of attenuation below the starting level of the test tone. Returns at each frequency demonstrate the repeatability of the procedure. Note that the occupant of Station 4 failed to push his "Don't Hear" button on the first trial of 2,000 cycles per second in the right ear, resulting in a reading of "90." The operator chose to repeat the test a third time at this frequency to verify the readings obtained on the second trial.

trial of the method with this end in view is being carried out at the U. S. Naval School of Aviation Medicine, Pensacola, Fla.

3. *The noise cumulator*. The second instrument developed for this study is called a noise cumulator. It is designed to measure the actual noise exposures incurred by personnel during military operations. It gives numerical measures of noise exposure in terms of the total duration of exposure to noise in specified frequency bands and above various preset intensity levels. The field use of the instrument involves tape recording the noise exposure experienced by a man during the actual performance of his job. This is accomplished by means of a frequency-modulated short-wave transmitter worn in the man's helmet, which broadcasts to the tape recorder those noises actually experienced at the wearer's head. Analysis of the tape recording is carried out later in the laboratory. The field unit, including microphone and transmitter, performs reliably and accurately in noise fields up to 150 db. The noise cumulator was used successfully on board the U. S. S. *Forrestal*. Considerable experimental work must still be done, however, to validate the measures obtained in terms of specified biological effects. Several different bases of acoustic analysis can be employed, depending on the choice of the method of rectification of the signal, the frequency bands, and the spacing of the intervals of intensity. Unfortunately, impulse type noises such as gunfire are still beyond the scope of the instrument. The particular measure or form of analysis must be found that correlates best with some specified effect. This will be a long and difficult task, but in the meantime the noise cumulator is already suitable for a basic survey of the actual current noise exposures that are associated with the operation of various aircraft and many other types of noisy equipment. If routine noise studies of the operation of new equipment are also carried out, any great increase in the noise exposure of service personnel can be detected or forecast in advance of actual field use.

THE ANEHIN FIELD STUDIES OF NAVAL PERSONNEL

During the years 1955 and 1956 many brief studies were conducted at the U. S. Naval School of Aviation Medicine to perfect the group audiometer and the various methods for psychologic, physiologic, and psychiatric testing. Considerable attention was devoted to the selection of tests suitable for use in the mobile laboratory under field conditions and to the collection of normative data. It was part of the original concept that a second laboratory at the U. S. Naval School of Aviation Medicine should also be maintained to develop new methods and to apply them to samples of naval personnel; and this type of work continues. Three field studies were successfully conducted.

The "Ticonderoga" Study

The first field study was carried out on board the U. S. S. *Ticonderoga* in two sessions, one during September-October 1955, and the other in May-June 1956. In 1955, preliminary sea trials were made using the mobile trailer laboratory. Audiometric measurements were made, and the various psychologic tests were tried out. In 1956, our psychiatrist colleagues, Capt. Philip B. Phillips, MC, USN, and Lt. William I. Stryker, MC, USNR, joined the ship in Istanbul, Turkey, at a time when the *Ticonderoga* had been operating in the Mediterranean for a period of 7 1/2 months. They administered questionnaires to and conducted standardized psychiatric interviews with a group of 70 selected personnel who had varying degrees of noise exposure in their different jobs. No definitive audiometric measurements or laboratory tests were conducted in connection with this second section of the study.

The "Forrestal" Study

The second study was carried out on board the U. S. S. *Forrestal* during its January-March 1956 training operations. In this study the feasibility of performing audiometry on board an aircraft carrier and also of measuring the noise exposure of personnel during operations by means of the noise cumulator was demonstrated. Psychologic and psychiatric tests were also successfully performed. This field study was more important as a demonstration of methods and their potentialities than as a source of definitive data, but the data and the qualitative impressions are all in agreement with those based on the two other studies.

The Cecil Field Study

Definitive studies of hearing and of psychologic performance were conducted in a third field study at U. S. Naval Air Station, Cecil Field, Fla., during the late summer of 1956 and early spring of 1957. The personnel selected for study in this case were chiefly maintenance personnel attached to various aircraft squadrons. The entire battery of tests, including audiometry, was employed in the summer of 1956 and then again after a period of approximately six months as a before-and-after study. The personnel included those who, by the nature of their jobs and the equipment with which they were associated, seemed to be the naval personnel incurring at this time the most severe noise exposures in terms of both intensity and duration. Control groups were selected from personnel who were not routinely exposed to jet noise.

LIMITATIONS OF THE ANEHIN STUDIES

Field Limitation

First, the ANEHIN study was a *field* study. The great advantage of a field study is that the results obtained are valid for the actual practical situation, but for this very reason it is more difficult to extract from the data any general statements or exact numbers. There are too many uncontrolled variables and extraneous factors, too much attrition of the original group in a test-retest study, and too little control of the major stimulus itself—in this case, the noise exposure.

Measurement of Noise Exposure

A second limitation is that there is no accepted, satisfactory measure of noise exposure. The noise exposures of flight deck and flight line maintenance personnel are brief exposures to noise of high but often rapidly changing intensity. The relations between intensity and duration for a given biological effect are unknown, and, until the noise cumulator is employed, the actual intensities and durations of operational exposures will not be known with any degree of precision. The independent variable, noise exposure, is therefore so vague that we cannot yet draw precise conclusions even when the dependent variable is measured numerically as decibels of threshold shift or as scores on well-standardized psychologic or physiologic tests. It was for just this reason, to define the noise exposures numerically, that the development of the noise cumulator was made a primary part of the project; but that development is only just now complete, and the present conclusions suffer accordingly in generality and in precision. We have been forced to rely on estimates of noise exposure based on questionnaires and on grouping men according to their jobs and according to the equipment used. We could do little more than give a rank order to the noise exposures of various groups as "high," "moderate," or "low," and sometimes only "more" or "less."

Neuropsychiatric Evaluation

Finally, in the area of neuropsychiatric evaluation the situation was even worse, because a neurologist's or psychiatrist's clinical judgment is a subjective opinion, based on many facts of observation and much previous experience. And it was to just this area of motivation, anxiety, fatigue, et cetera, that most of the anecdotal evidence of the BENOX Report pointed as the likeliest place where undesirable nonauditory cumulative aftereffects might be found. We therefore undertook to develop better methods of observation and evaluation, first by systematically standardizing the psychiatric interviews so that the same areas would be explored in all cases, and, second, by developing a psychiatric rating scale to make the evaluation of

the information more objective and reliable. This development is still incomplete, however, and, like the noise cumulator, it must still be validated. For the present, then, although the results obtained with the psychiatric rating scale are given in the full U. S. Naval School of Aviation Medicine Report, we still were forced to rely largely on the clinical impressions and judgments of our two psychiatrists. Fortunately, both of them were naval officers, and, therefore, had a background of appropriate clinical experience.

CONCLUSIONS AND RECOMMENDATIONS

Because of the limitations mentioned above, our results are neither all yes and no, nor sharply black or white. There are large gray zones of uncertainty in between, and because we cannot say "yes" it does not mean that the answer is necessarily "no." We do have at least partial answers to the following practical questions:

1. Should present operational procedures be modified, or are new types of protective equipment required, to protect military personnel from the cumulative ill effects of present noise exposures?

2. Are the new criteria for hazardous noise exposure too lenient? Are they too strict?

3. What of the future, with its expected increase in the noise levels of jet engines and other noise sources?

4. What recommendations emerge for the protection of personnel and for further study?

With practical questions, a precise scientific statement of fact does not constitute a complete answer. In addition, some kind of value judgment is involved or some extrapolation into the unknown is expected. The scientific data that we have, with our statistical analyses, will appear in a report to be issued by the U. S. Naval School of Aviation Medicine. The collective judgments of the ANEHIN group on the practical questions listed above, and a brief statement of the kind of data upon which each judgment is based, are as follows:

As of March 1957 there was no reasonable cause for immediate alarm concerning cumulative ill effects from the operational exposure of personnel to jet engine noise. We see no present need for changes in operational procedures or for protective equipment other than ear protectors of types that are currently available.

We have no evidence that the criteria of 1957 for hazardous noise exposures should be made more strict, nor can we say with assurance that they are too lenient. They lie within the zone of uncertainty of our conclusions.

Some of our findings suggest, but do not prove, that present operational exposures to jet engine noise may be near the limit of producing permanent impairment of hearing and also a general impairment of performance on a wide variety of psychologic tests. With increased noise exposure these effects may become not only clearly measurable but also of practical medical or operational significance. Efforts should therefore be continued to establish clearly the limits of tolerance for noise exposure by: (a) controlled laboratory experiments with volunteer subjects; (b) continued monitoring of actual operational noise exposures; (c) routine monitoring audiometry for all seriously noise-exposed personnel; (d) monitoring by selected psychologic tests of sample groups of the personnel who incur the most severe noise exposures; and (e) continual alertness of military medical officers to psychiatric or other medical indications of increased stress, either general or specific, associated with habitual noise exposure.

The most urgent research need is to develop a valid measure of noise exposure, such as the noise cumulator may provide, and to apply it to men during operational procedures with current and also with future noisy military equipment.

If adequate measures of actual and expected noise exposures are made, and *if* routine monitoring audiometry and also small sample psychologic and physiologic monitoring of highly noise-exposed personnel are instituted, then it will be legitimate to transfer some research effort from the problem of possible cumulative ill effects of noise exposure to the more urgent problems of the impairment of performance, including communication, in the actual presence of intense noise.

If and when a substantial increase in noise exposure occurs, due either to the introduction of noisier equipment or a change in operational procedure, a new study of cumulative effects should be undertaken by methods similar to those used in the present study.

ANALYSIS OF OBSERVATIONS

Noise Measurement

Measurements of the noise exposure experienced by several members of a flight deck crew were made aboard the U. S. S. *Forrestal* in March 1956. These preliminary measurements were concentrated on two members of the flight deck crew whose duties were such that they apparently were exposed to more intense noise than others. The measurements were accomplished by means of a miniature frequency modulation (FM) transmitter worn by the observer, an FM antenna on the flight deck next to the catwalk, and a fixed FM receiver and tape recorder located below deck. Figure 3 shows a record of the exposure of the forward plane director during a typical launch.

Cumulative distributions of noise level versus exposure time were obtained from a specially designed instrument, the noise cumulator. Operational exposures to very high-intensity noise
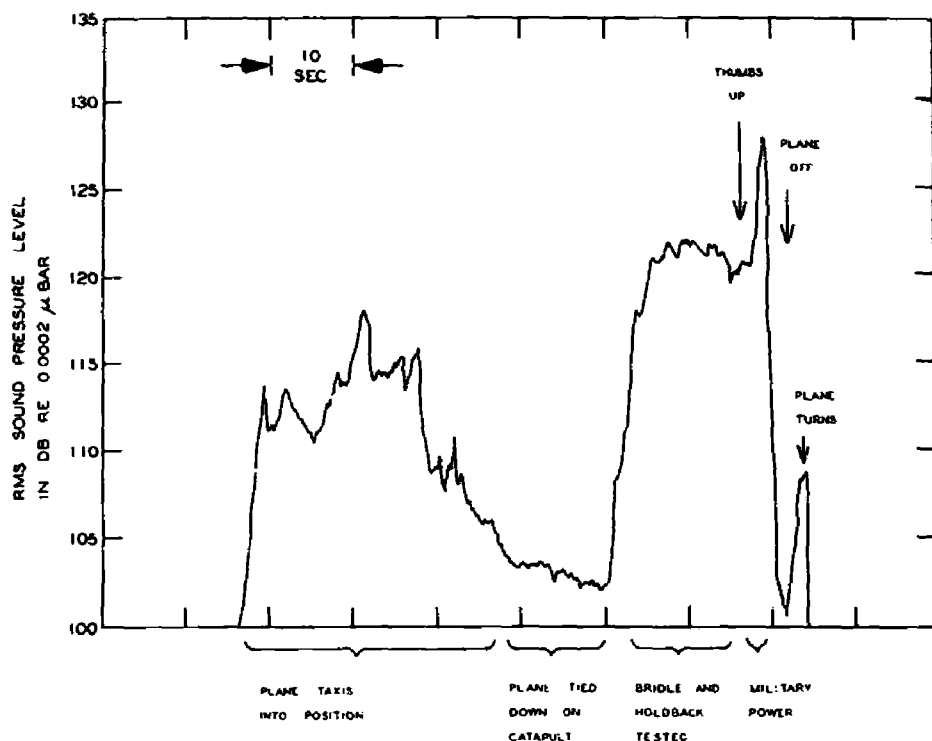

Figure 3. Over-all sound pressure level to which the forward plane director is exposed during a typical launch. The aircraft is the F7U-3 without operation of the afterburner.

are extremely brief (fig. 4). The duties of one of the men studied, the forward plane director, placed him in the center of the deck 20 to 50 feet behind the catapults. The second man studied was responsible for attaching the holdback mechanism to the rear of the airplane on the catapult. Both men appeared to spend more time than any others in the high-intensity regions of the sound field behind jets. However, neither man experienced peak levels in excess of 138 db for more than about 3 seconds during an average launch. As many as 100 launches in a day would produce less than 5 minutes' total exposure to such levels. Even exposure to peak levels above 115 db would total less than 1 1/2 hours daily.

This exposure to noise is significantly less than had been assumed in considerations of the possible hazards associated with noise exposure aboard aircraft carriers. The brevity and infrequency of exposure to extremely high noise levels has a very important effect on the noise exposure. This effect can be demonstrated by estimates of the equivalent steady exposure

experienced by a few members of the flight deck crew. The "equivalent exposure" is the level of steady noise sustained throughout an 8-hour day that would deliver the same total sound
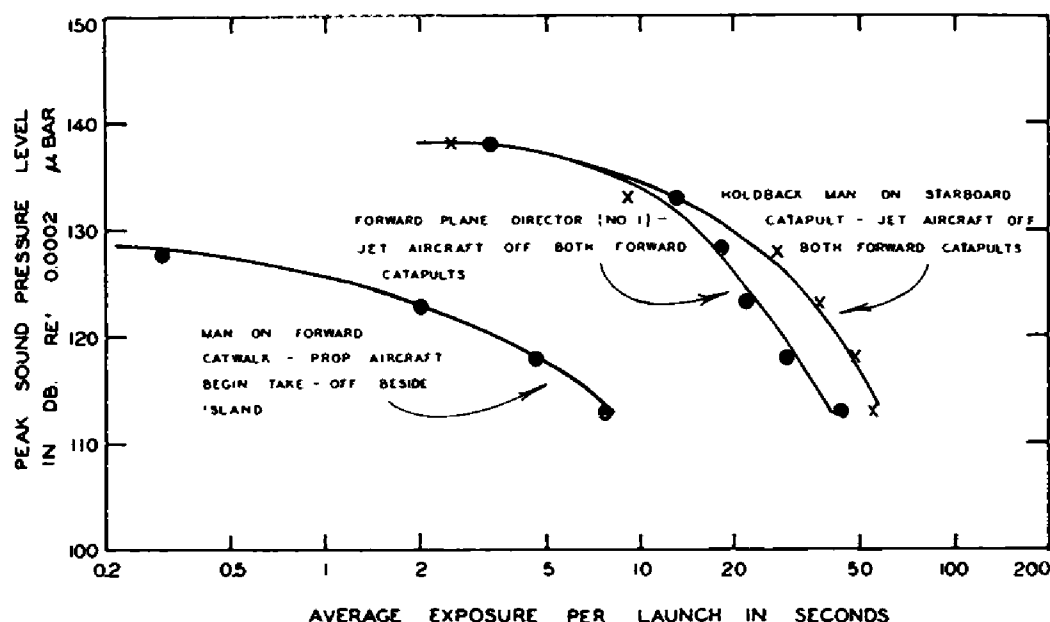

Figure 4. Cumulative distribution of peak-sound pressure level versus exposure time for two members of the flight deck crew. The exposure time is computed by averaging the results of several launchings. Data on exposure for a man stationed in the forward catwalk during the take-off of propeller aircraft is shown by way of contrast. These aircraft began the take-off roll near the island. The peak sound pressure level for jet engine noise is about 10 decibels (db) greater than the root mean square (rms) sound pressure level.

energy to the ear as does the actual noise exposure. An average daily launching of about 40 jet aircraft is assumed. The exact number launched is not critical since a change in this number by 50 per cent is no greater than the probable error of ± 1.5 db in the noise measurements. The equivalent exposure level is shown below for the two men studied in detail:*

	Equivalent rms SPL
Forward plane director - jet aircraft	105 db
Holdback man - jet aircraft	105 db

The estimates given above hold only for exposures to the particular combinations of planes aboard the U. S. S. *Forrestal* during March 1956. They assume that afterburners are not employed.

Auditory Effects

The most significant audiometric study in the ANEHIN Project was made at the U. S. Naval Air Station, Cecil Field, Fla. In

*The equivalent exposure level is in terms of the root mean square (rms) sound pressure level (SPL) re 0.0002 microbar. For typical jet engine noise the rms value is about 10 db less than the peak level.

August 1956 audiograms were obtained on 1,200 Navy enlisted men who were normal by otologic examination, including 579 men with some history of regular exposure to jet engine noise, and 379 with little or none. Among the latter were 91 men under 25 years of age who had not been exposed to large-caliber gunfire. These 91 men served as a "biological baseline." Their hearing was similar to that of similar groups in previous survey studies. In the initial audiograms, hearing losses were slightly greater among those men who were, or who had been, exposed to noise from reciprocating engines or from jets without afterburner. It is not certain from this cross-section study, however, that the engine noises had produced these hearing losses. Another probable cause of the greater hearing losses was gunfire. Almost twice as many of the "noise-exposed" personnel in the age groups 17 to 22 and 23 to 28 years had been subjected to large caliber gunfire. They also reported more tinnitus following their exposure to gunfire. The greater tinnitus suggested that, on the average, the severity of noise exposure may have been significantly greater for this group than for the "non-noise-exposed" group.

More significant than these moderate initial losses, however, are the follow-up audiograms taken of 220 of these same men in squadrons that were flying jet planes with afterburners. These were the men who presumably received the most severe noise exposures in the interval, yet they showed on the average *no additional hearing loss after seven months of routine activity.* A similar negative result also was found in our study of flight deck personnel during a three months' training cruise aboard the U. S. S. *Forrestal* in 1956.

The results of audiometric study at Cecil Field are presented and analyzed in considerable detail in an article by Ward.[5] Here the possible complications resulting from temporary threshold shift and from some increase in the use of protective equipment are considered carefully. A small additional impairment of hearing may have occurred during the seven months of noise exposure, but if so it was obscured by these factors that could not be controlled. The possibility that the men with initially greater hearing losses might be those who are more susceptible to incurring additional hearing loss from additional exposure also was examined, but no indication was found that men with pre-existing losses are more likely to suffer additional losses than men with normal hearing.

Obviously, the negative results of this study of men before and after seven months of routine operational exposure to jet engine noise is most reassuring. The results should not be interpreted, however, as contradicting in any way the criteria that have been established by other groups for hazardous noise exposure, particularly for exposure to steady industrial noises.

The criteria were developed on the basis of many years of noise exposure, while the present study extended for only seven months. The number of men who could be studied before and after this seven-month period under comparable conditions is not very large, and the expected slight trend toward increased hearing losses may be obscured by the many other factors that were involved. It is worth noting, however, that negative results very similar to the present ones have been obtained in other studies in which men exposed to aircraft noise have been monitored over a period of time. Sataloff,[6] in a five-year study of men working around jet engine test cells, found only slight changes, and even these could not be attributed unequivocally to noise. Similar negative results recently were reported by Kopra[7] in a study of Air Force personnel.

Nonauditory Effects

The search for nonauditory effects was also largely negative. In the preliminary studies aboard the U. S. S. *Ticonderoga* and the U. S. S. *Forrestal* no large differences were found between groups of noise-exposed and non-noise-exposed subjects. The final study at Cecil Field consisted of three parts: First, a group of 16 psychologic tests was administered twice to the same personnel, with an interval of six months between tests. Second, sick-call records were analyzed according to total frequency of reports to sick call. Third, a group of nine paper-and-pencil tests was given during the final testing period.

The battery of psychologic tests had been selected in order to sample as widely as possible a variety of different sensory, psychomotor, and intellectual functions. Twenty-five tests were employed in all: critical flicker frequency, tapping speed, reaction time, fine hand steadiness, gross hand steadiness, standing steadiness, and Knox Cube Test, fine dexterity, the Digit Symbol Test, tests of visual acuity, phoria, and depth perception, the Cornell Index, the Saslow Screening Inventory, the Taylor Anxiety Scale, and, in addition, nine factored aptitude tests that were given only at the end of the six-month period.

Analysis of the results of the initial tests given at Cecil Field in August 1956 showed no large differences between men having a history of exposure to jet noise and those having had no previous noise exposure. Our primary interest, however, was in assessing *changes* in test performance following the six-month period between tests as related to the severity of noise exposure during this period. A major difficulty in accomplishing this was the estimation of relative noise exposures of the different groups and individuals. Actually, three different estimates of noise exposure were employed. Subjects were divided into "most-exposed" and "least-exposed" groups on the basis of (1) the amount of noise generated by the plane which their squadron used, (2) the estimation (based on responses to a

questionnaire) of a man's noise exposure during the six-month period between tests, and (3) changes in his auditory threshold during the period between tests.

No positive relationships were found among the three above-named criteria for severity of noise exposure. That is, a man judged to be severely exposed by one criterion would not necessarily be judged to be severely exposed by either of the other two criteria.

In all, 95 of the men who were given the nonauditory tests at the beginning of the six-month period were retested at the end of the period. Six of the tests, which could be administered to 10 men at a time, were given to all the subjects. The remaining 10 tests, which required individual administration, were given to 31 of the men.

Each of the six tests that were given to all the men was analyzed according to each of the three exposure criteria, and in the resulting 18 statistical comparisons* there was only one case where the "most-exposed" group performed significantly worse (at the 5 per cent level of confidence) than the "least-exposed" group. The 10 tests given to the 31 men were analyzed only according to the criteria of individual exposure estimates and squadron assignment, because only four subjects in this group exhibited any hearing impairment. The 20 statistical comparisons that were made with this group of tests revealed no statistically significant differences between the "most-exposed" and the "least-exposed" groups.

The "most-exposed" group thus showed a significant deterioration of performance on only 1 out of 38 statistical comparisons. This one significant difference obviously could have occurred by chance, and it can safely be concluded that no adverse effects of noise exposure were demonstrated for this group of tests.

Although there is no statistical evidence of effects of exposure, nevertheless, on 26 of the 38 comparisons, the "most-exposed" group actually performed worse, even though only slightly worse, than the "least-exposed" group.

The reports to sick call by 183 men were analyzed for the total number of reports to sick call during the six-month period before the initial tests and also during the six-month period between tests. Changes in frequency of reports to sick call were analyzed according to the three criteria for noise exposure. The

*For the original analysis of nonauditory data the initial test score was subtracted from the retest score for a given test, and groups of subjects were compared in terms of absolute change in performance between the time of initial test and retest. Two of the discussants at the CHABA conference pointed out that use of the analysis of covariance technic would provide a more refined estimate of performance changes. Accordingly, all of the nonauditory data were reanalyzed by this method, and the results of the reanalysis are presented here.

"most-exposed" group showed a larger increase in frequency of sick call reports according to two of the three criteria, but none of the differences were statistically significant.

The results of the nine factored aptitude tests were analyzed according to an estimate of noise exposure from questionnaire information. Inasmuch as performance on seven of the nine tests should be correlated with intelligence level, the intelligence level of the groups was statistically equated by use of analysis of covariance. The "most-exposed" group gave the poorest performance on eight of the nine tests, but in only one case was the difference between groups statistically significant (at the 5 per cent level of confidence).

We can conclude with some confidence from the above analysis that the results in the nonauditory performances tested give no indication of a serious change for the worse as the result of greater noise exposure. Again the negative result is reassuring, even though the battery of nonauditory tests was not as extensive nor was the number of subjects tested as large as we had originally planned. The result is not entirely negative, however, because the "most-exposed" group performed worse, even though only slightly worse, than the "least-exposed" group on 36 out of a total of 50 comparisons.

Psychiatric Effects

In the psychiatric study aboard the U. S. S. *Ticonderoga* in May of 1956, the examinations and interviews were carried out when the *Ticonderoga* had been operating in the Mediterranean for 7 1/2 months. Due to unforeseen circumstances the cruise had twice been prolonged beyond the usual six months' time. During the 7 1/2 months, about 1,500 catapult shots had occurred.

A group of 70 men were selected, all with General Classification Test (GCT) scores above 30, who had all been present aboard the *Ticonderoga* for at least 75 per cent of the cruise. The majority of these men were flight deck personnel, although not all worked in close proximity to the forward catapults, and a small control group of men worked below decks with little or no exposure to noise. The men were classified with respect to noise exposure on the basis of their jobs. Thirteen had "very high" noise exposures, 18 had "high" noise exposures forward of the island structure, 13 had "moderate" noise exposures at or aft of the island, and 14 had relatively "low" noise exposures.

Psychiatric rating scores were obtained for each of these men by a rather elaborate method that cannot be described in detail in this article but which aims to divide the men into a "more adjusted" group and a "less adjusted" group. The mean scores of the four exposure groups differed but little, but when a cutting score was employed there seemed to be a significant

difference between the groups. The direction of the difference associated high noise exposure with deterioration of motivation or some increase in anxiety.

In addition to employing the standardized questionnaire and interview and the predetermined scoring system, the psychiatrists also noted the comments made by individual men and evaluated their reactions. Many of the subjects gave anecdotal reports similar to those in the BENOX Report. The most common complaints were increased irritability, tenseness, insomnia, and occasionally fear because of inability to communicate with other men in the presence of noise. With the exception of the difficulty of communication, however, most of the men stated that they did not believe that their trouble was due to the noise. They felt much more strongly that their trouble was due to the general dangers of the job and to further concern about a delay in their return to the United States that had been occasioned by a change in the schedule of operations of the ship.

The relative danger associated with the various jobs, therefore, was assessed. It appeared that there was indeed a greater degree of risk for the men in the very high noise exposure and the high noise exposure groups as compared with the low exposure group. The relation between the psychiatric rating scores and the probable danger associated with the job seemed to be at least as high as, and perhaps higher than, the relation between rating scores and noise exposure. This conclusion, reached by the psychiatrists from their own observations, was borne out by the statements made by the subjects themselves. Among the men working in the most dangerous jobs (involving also very high noise exposures) 92.3 per cent expressed anxiety about their jobs, while among the men working on the safest jobs just below the flight deck only 21.4 per cent expressed any anxiety about their jobs. Very few men, however, even among the high noise-exposure group, expressed the opinion that the jet noise was disturbing to them.

The over-all subjective impression developed in May 1956 by the two psychiatrists aboard the U. S. S. *Ticonderoga* was that the anxiety level among the men working on the flight deck was considerably greater than what they had encountered among a similar group of men interviewed aboard the same ship in the previous September, about eight months earlier. Unfortunately the overlap between the earlier group studied and the final group was too small and the differences and the methods of interview employed were too large to allow any significant comparison of scores for the same individuals before and after the 7 1/2-month cruise.

It is the over-all opinion of the psychiatrists that the basic reasons for the increased anxiety revealed in the psychiatric

interviews lay in the greater awareness of the inherent dangers of the jobs and in the fact that the ship was overdue for return to the States. The awareness of danger had undoubtedly been heightened by several fatal accidents that had occurred on the flight deck during the cruise. Furthermore, whatever the neuro-psychiatric effects of high noise exposure may be, they are subtle and difficult to extract. The present series of carefully planned and carefully conducted interviews did not reveal any easy or obvious correlations with noise exposure, nor do they give any cause for alarm.

The general conclusion from our auditory, nonauditory and psychiatric observations is, therefore, that no one of the many functions examined in this series of nonauditory tests stands out clearly as being adversely affected by noise exposure ac-cording to any one of the three admittedly imperfect criteria used for estimating the severity of the noise exposure. There is, however, a definitely suggestive trend in the direction of a slight over-all decrement of performance associated with the most severe noise exposures. Noise levels as of March 1957 did not constitute a serious threat for exposed personnel in terms of large changes in performances on our test battery. Be-cause of the suggested trend toward a slight general decrement, however, we must view with some concern the future effects of higher noise levels and longer periods of exposure. The negative conclusions apply only to a period of six months' ex-posure to noise sources as powerful as the F4D.

FINAL EVALUATION

The over-all result of the ANEHIN survey is definitely reas-suring. Some initial auditory impairment was found among naval personnel, as in the previous survey, but it could not be proved that six months' operational exposure to jet engine noise, even with afterburners, increased the auditory impairment. None of the nonauditory tests showed any really clear correlation between worse performance and greater exposure to jet engine noise. There was a slight increase in the number of sick calls and a trend toward a very general nonspecific lowering of test per-formance, but these were merely trends. An increase in anxiety and tension was found among flight deck personnel near the end of a 7 1/2-month Mediterranean cruise, but the anxiety and tensions were probably caused by hazards and stresses other than jet engine noise.

Why, after the solemn warnings of the BENOX and CHABA reports, was so little evidence of any cumulative injurious effects of exposure to the high-intensity noise of jet engines found?

There are three definite and one rather vague answers to this question. (1) The increase in the noise produced by operational

aircraft in the fleet did not occur as soon as appeared likely when the BENOX and CHABA reports were written. One particularly noisy type of airplane never became operational and another was slow in reaching full employment. (2) The introduction of more powerful catapults had greatly reduced the use of the afterburner at take-off. This has reduced the anticipated noise exposure on the carrier deck by several decibels. (3) The really severe noise exposures on the flight ·deck were, and still are, very, very brief.

It is for these three reasons that the ANEHIN Project found itself in the field in good time, ahead of the great anticipated increase in noise exposures on shipboard. For these reasons ANEHIN could properly transfer its activities ashore to the U. S. Naval Air Station, Cecil Field, Fla., where the maintenance men who service jet planes with afterburners actually incur much more severe and prolonged noise exposures than do the carrier flight deck personnel.

Even among the shore-based maintenance men, the results are almost, although not quite, negative. This is sheer good fortune. The vague conclusion is that Nature's margin of safety proves to be a little wider than the authors of the BENOX report feared it might be. For the present, then, reasonable caution, observance of criteria for noise exposure, use of personal protective equipment, and the institution of appropriate monitoring procedures should suffice. How wide the present margin of safety may be we do not know, but for the present we believe that further field studies of cumulative aftereffects are not needed except as part of a sampling, spot-check type of monitoring. If the limits of tolerance for high-intensity noise exposure are to be sought, the job can be done much more cheaply and effectively under controlled conditions, as in a laboratory, than as a field study.

Our final words are again a reassurance as to the present situation, followed by a warning against overconfidence and complacence in regard to the future. We still have not encountered the noise stresses foreseen in the first CHABA Report.

DISCUSSION

Doctors Nello Pace, R. C. Davis, Lyle Jones, David McK. Rioch, and William Burns briefly discussed the report.*

Doctor Pace remarked that relatively simple tests of adrenal cortical function based on blood and urine samples might detect underlying

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physiologic changes, even though the person appears to be unaffected in terms of his ability to perform under stress. Doctor R. C. Davis noted that the autonomic nervous system may participate in the adjustment of the body to stress and the maintenance of performance. Doctor Jones commented that the statistical technic of analysis of covariance would partial out undesired variables, especially those associated with the unreliability of a given physiologic or psychologic measure. He suggested that the use of this technic in recalculating some of the statistical data would result in much more meaningful and useful data. Doctor Rioch added that field studies often have as their major result the identification of the relevant factors in the problem and the observations that need to be made. In addition, new apparatus is frequently developed that has applications beyond the situation for which it was created. The ANEHIN noise cumulator is a major contribution to the study of noise exposure in general.

Doctor Burns briefly reviewed the British Navy's research on hearing conservation in high-intensity noise. The Royal Navy is placing great stress on educating service personnel on the necessity of protecting their hearing in the presence of high-intensity noise. Otherwise, the British work is of the same general character as the American effort, with much the same conclusions. The American V-51R ear plug is now being superseded on the carrier flight deck by the British MK-1 helmet equipped with an ear muff that incorporates a leather sealing ring as well as an acoustic valve. Other improved models of the muff are now being introduced.

SUMMARY

Carrier flight deck personnel on board the U. S. S. *Forrestal* and the U. S. S. *Ticonderoga*, and shore-based jet aircraft personnel at the U. S. Naval Air Station, Cecil Field, Fla., were tested by pure-tone audiometry, psychologic and psychomotor performance tests, group paper-and-pencil tests, psychiatric interviews, and analysis of sick-bay calls. The results were related to the estimated relative noise exposures of the various exposed and control groups tested.

The audiometry was conducted in a specially designed and constructed trailer laboratory by means of a group audiometer that was developed as part of the project. This semiautomatic instrument is suitable for monitoring audiometry elsewhere.

A method for the measurement of the total noise exposure of individuals during actual military operations or maintenance tasks was developed. This method relies upon a special device, the "noise cumulator," which was designed, constructed, and a prototype tested on board a carrier. The complete device was not, however, available until after the three field studies. This instrument is suitable for monitoring the noise exposures to be expected from future aircraft.

The battery of psychologic and psychomotor tests was composed of simple, well-tried tests of known significance that sampled a wide variety of sensory, motor, intellectual, and emotional functions.

No clear, positive effects, either auditory or nonauditory, of exposure to noise were shown by any of our tests. Certain small positive effects were found by the audiometric and the psychiatric studies, but these are attributed to causes other than jet engine noise. A suggestive trend tov.ard a slight general decrement in performance did appear in the psychologic tests of jet plane maintenance personnel.

CONCLUSIONS

As of March 1957, there was no reasonable cause for immediate alarm concerning cumulative aftereffects of jet-engine noise exposures of naval personnel.

It is unsafe to extrapolate from present noise exposures to the more severe exposures that must be anticipated in the future. The extent of the present margin of safety is not known, and continued vigilance is required.

In the opinion of the ANEHIN group, at least two other undesired effects of high-intensity noise were, as of 1957, more serious threats to military operations than were its cumulative aftereffects. They were (1) interference with communications, and (2) decrement in performance of personnel during actual exposure to high-intensity noise.

RECOMMENDATIONS

Further field studies of this sort are not necessary until there is a considerable increase in operational noise exposures. Meanwhile, monitoring of noise exposures with the equipment developed by ANEHIN should be instituted to detect such changes.

Monitoring audiometry and also monitoring by selected psychologic and psychomotor tests should be instituted for the protection of personnel who suffer the most severe noise exposures.

Valid criteria of hazardous noise exposures should be established by carefully controlled experiments with human volunteers, using careful measurements of noise exposure and the tests of the ANEHIN battery. In such experiments the decrement of performance during actual exposure to noise also should be measured.

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SPINNING IN A SPACESHIP

"From observation of the V-2 and Viking it appears that these rockets spin fairly rapidly and unpredictably on their upward flight and simple analogy shows what the effect of this might be on the human body. If you spin round and round while standing in the one position and then stop, what happens? Everything else in the room appears to spin and you probably feel giddy. If you now try to pick something off the floor or table you experience great difficulty in doing so. This is what would happen in the rockets of today only to a greater degree. If the spinning occurs at right-angles to this, that is if the crew were seated in the spaceship, then spinning would be round an axis fore and aft through the body at the lower end of the chest. In this situation consciousness is lost fairly quickly and death might even occur. Although spinning is obviously a serious hazard it is one which can be avoided by design, and in the future rockets will require to be stabilized."

—M. KENNEDY BROWNE, B. Sc., M. B., CH. B.
in *Spaceflight*
p. 142, July 1957

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